Fractional order sliding mode control for power quality improvement in the distribution system

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ABSTRACT

This paper presents fractional order sliding mode control (FOSMC) based distribution system compensator (DSTATCOM) for power quality improvement in the distribution system. The three-phase two-level inverter-based voltage source converter (VSI) with DC-link capacitor is used as DSTACOM. In this paper, the FOSMC-based DSTATCOM improves supply current harmonics, load balancing, and reactive power and reduces THD. The sinusoidal pulse width modulation (SPWM) is generating gating pulses for VSI. The performance of the presented system is verified in MATLAB/Simulink software. The simulations are verified source voltage, current and load current as well as compensating current. The FOSMC has maintained a constant supply current when connecting non-linear load. The hardware results are also presented in the manuscript. The hardware results are supply current, voltage, compensating current, and load current.

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1. INTRODUCTION

Power quality issues are one of the challenge tasks in modern society. The developments of world as well as problems are rapidly changes. Voltage fluctuations, unbalanced load, and grid complexities are the common problems in the distribution system, for compensating for these problems authors presented FOSMC. This reference DSTATCOM is controlled by FOSMC. The proposed technique injected as well as absorbed reactive power in the distribution system. The performance of the FOSMC results had compared with the PI controller. The proposed controller results had superiority, rapid tracking, fast convergence and low THD [1]. Grid harmonics are a very serious problem in distribution, for compensation grid harmonics authors implemented neural-network-based SMC. The presented technique effectively eliminated grid harmonics [2]. The oscillations are one the serious problem in wind farm-based distribution systems, for eliminating this oscillation the authors presented FOSMC-based DSTATCOM. The presented controller effectively eliminated harmonics and compensated active and reactive power wind generation [3]. The fixed frequency SMC proposed an energy management system for the battery. The proposed controller had a robust non-linear controller which minimized the chattering phenomenon. This paper proposed controller results compared with PI controller [4]. FOSMC suppressed chattering from power and current signal in the distribution system [5]. The most of the research papers focused on current related harmonics in literature. Some other researchers are focused reactive power compensation using conventional PI and SMC controller.

Robust fuzzy FOSMC eliminated grid current harmonics in the distribution system. This paper's Kalman filter minimized the sampling sensors. The Lyapunov theorem analyzed the stability of the system [6]. Grid-connected doubly fed induction generator controlled by FOSMC. The proposed controller

mitigated the chattering phenomenon in the sliding surface. The controller mitigated grid voltages [7]. The FOSMC controller minimized frequency deviation in the power system [8]. The FOSMC controller is implemented for remote electrification systems. The presented controller had well-operated in the distribution system [9]. The hybrid energy system is controlled by FOSMC; the source is wind, solar and grid [10]. Grid-connected inverter controlled by FOSMC, the inverter capacity is 10 kW [11]. The FOSMC mitigated sub synchronous oscillations in wind farms [12]. The micro grid is controlled by FOSMC, the micro grid inputs are wind, PV, and fuel cells [13]. The overall literature review researchers reduced harmonics and improved steady-state and transient-state performance of the power system. This paper organizes section two proposed topology, section three presents control scheme and section four presents result and last section conclusion. The main objective of this paper is reducing source side harmonics using FOSMC.

2. DSTATCOM TOPOLOGY

FACTS devices are commonly used for the compensation of reactive power transmission and distribution systems [14]–[17]. The FACTS devices are mainly classified into three categories; those are shunt compensation, series compensation, and both series and shunt compensation (UPFC). The shunt compensators classify into two sub-categories. Thyristor-based shunt compensation and converter-based shunt compensation. This paper presents voltage source converter-based shunt compensation named DSTACOM shown in Figure 1. Generally, STATCOM is used for controlling the transmission system. This paper presents DSTATCOM, this DSTATCOM controlling distribution system such as reactive power, load balancing, and power factor correction. This DSTSTCOM is injecting reactive power when required distribution system and observes reactive power when excessive reactive power is in the distribution system.

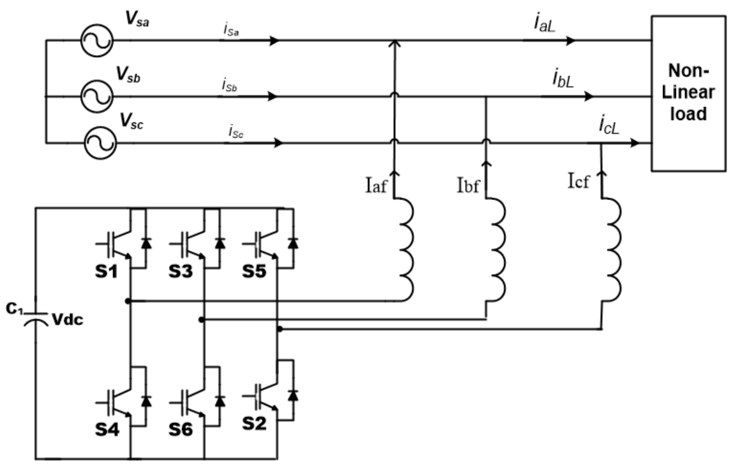


Figure 1. DSTATCOM topology

3. FOSMC CONTROL SCHEME

Figure 2 shows the FOSMC control scheme. The V_{dc} and V^{*}dcare the DC-link and reference DC-link voltage [18]–[21]. The load currents are I_{aL}, I_{bL}, and I_{cL}. The compensating currents are I_{af}, I_{fL}, and I_{cf}. The I_{dL} and I_{qL} are the d-axis and q-axis load currents. The I_{df} and I_{qf} are the d-axis and q-axis compensating currents. The control scheme has a low pass filter used for the compensation of harmonics.

$$\frac{di_{abcLV}}{dt} = \frac{-Ri_{abcLV}}{L} + \frac{V_{abcsat}}{L} - \frac{V_{abcLV}}{L} \tag{1}$$

$$\frac{di_{dLV}}{dt} = \frac{-Ri_{dLV}}{L} + \omega i_{qLV} + \frac{V_{dc}^{m}}{2L} - \frac{V_{dLV}}{L} \tag{2}$$

$$\frac{di_{qLV}}{dt} = \frac{-Ri_{qLV}}{L} - \omega i_{dLV} + \frac{V_{dc}^{m}}{2L} - \frac{V_{qLV}}{L} \tag{3}$$

The (4) and (5) are modified (2) and (3) with the addition of model uncertainty $(\rho d, \rho q)$.

$$\frac{di_{dLV}}{dt} = f_d\left(V_{dLV}, V_{qLV}, i_{dLV}, i_{qLV}\right) + xm_d + \rho_d \quad (4)$$

$$\frac{di_{qLV}}{dt} = f_q\left(V_{dLV}, V_{qLV}, i_{dLV}, i_{qLV}\right) + xm_q + \rho_q \quad (5)$$

where, $x = \frac{V_{dc}}{2L}$ (6)

The (7) and (8) are non-linear functions, expressed as:

$$f_d = \frac{di_{dLV}}{dt} = \frac{-Ri_{qLV}}{L} + \omega i_{qLV} - \frac{V_{dLV}}{L} \quad (7)$$

$$f_q = \frac{di_{qLV}}{dt} = \frac{-Ri_{qLV}}{L} + \omega i_{dLV} - \frac{V_{qLV}}{L} \quad (8)$$

The (9) and (10) are the proposed FOCSMC non-linear sliding surfaces.

$$S_d = e_d + \lambda D^{\alpha-1}(sig(e_d)^{\gamma}) \quad (9)$$

$$S_q = e_q + \lambda D^{\alpha-1}\left(sig\left(e_q\right)^{\gamma}\right) \quad (10)$$

Where $e_d = i_{dref} - i_{dLV}$ (11)

$$e_q = i_{qref} - i_{qLV} \quad (12)$$

$$sig(x)^{\gamma} = |x|^{\alpha} sin(x) \quad (13)$$

$$sin(x) = \begin{cases} \frac{x}{|x|}, & if x \neq 0 \\ 0, & if x = 0 \end{cases} \quad (14)$$

The (15) and (16) are the proposed sliding surface equation with the inclusion of the RL function is writes as [22]–[25].

$$S_d^* = i_{dref}^* - i_{dLV}^* + \lambda_{RL} D^{\alpha}(sig(e_d)^{\gamma}) \quad (15)$$

$$S_q^* = i_{qref}^* - i_{qLV}^* + \lambda_{RL} D^{\alpha}\left(sig\left(e_q\right)^{\gamma}\right) \quad (16)$$

$$\dot{S_q} = f_d(\cdot) + xm_d + \rho_d + \lambda_{RL} D^{\alpha}(sig(e_d)^{\gamma}) \quad (17)$$

$$\dot{S_q} = f_q(\cdot) + xm_q + \rho_q + \lambda_{RL} D^{\alpha}\left(sig\left(e_q\right)^{\gamma}\right) \quad (18)$$

Based on and (18), the proposed control law estimated reference current error convergence. Modulating signals (19) and (20) for SPWM can be written as:

$$m_d = \frac{-[f_d(\cdot) + \lambda_{RL} D^{\alpha}(sig(e_d)^{\gamma}) + k_d sgn(s_d)]}{x} \quad (19)$$

$$m_q = \frac{-\left[f_q(\cdot) + \lambda_{RL} D^{\alpha}\left(sig(e_q)^{\gamma}\right) + k_q sgn(s_q)\right]}{x} \quad (20)$$

Figure 3 presents the FOSMC control scheme, the control scheme implemented from control system by using state space matrix equations. The main elements of this control scheme are input parameters, output parameters, feedback loop and DC link control scheme. The plant is connected MOSFET input, the SMC mainly have two components one control law and switching law. The sig(.) is used for soft switching function. The eq inputs are direct axis currents, these currents are reference current actual current. The FOSMC is one of the robust control techniques.

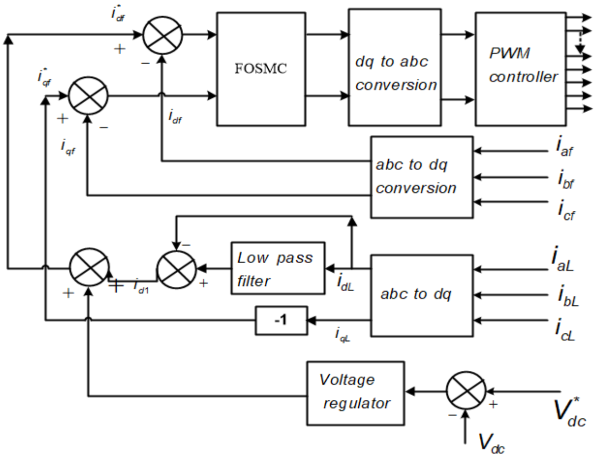


Figure 2. FOSMC control scheme

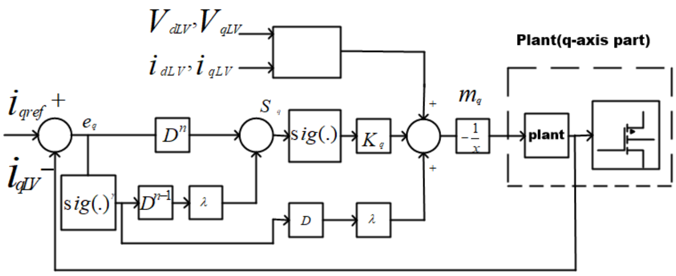


Figure 3. Control diagram of FOSMC for DSTATCOM in q-axis

4. SIMULATION RESULTS

Figure 1 shows the proposed D-STATCOM topology. The proposed topology is controlled by FOSMC with P-Q reference frame theory. The SPWM technique generated PWM pulses for the VSC converter. The proposed topology was simulated by using MATLAB/Simulink software.

Figure 4 shows the single-phase output waveforms. Figure 4(a) single phase supply voltage, the system simulation run time 0.1 sec. the system voltage maintains a constant 230 V. The supply voltage is represented by Vsa. Figure 4(b) shows the compensating current, represented by Iaf. The compensating current is compensated reactive power in the system. Without a compensator, the load current is equal to the supply current. Figure 4(c) shows the supply current, the current is represented by Isa. The current take 0.025 sec for the steady-state position. The magnitude of the supply current is 40 A. Figure 4(d) shows the load current waveform, represented by I_{aL}. Table 1 shows the simulation results parameter table.

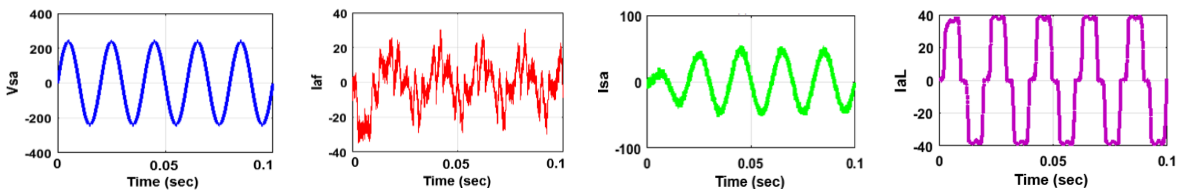


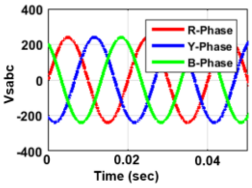
Figure 4. Singe phase output waveforms (a) supply voltage, (b) compensating current, (c) supply current, and (d) load current

Table 1. Simulation results

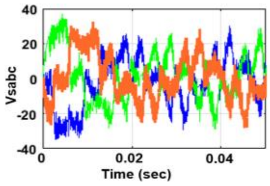
S.L.	Criteria	Achievement	S.L.	Criteria	Achievement
1	Supply current	40 A	4	Load voltage	230 V
2	Supply voltage	230 V	5	DC-link capacitor	470 V
3	Load current	40 A			

Figure 5 shows the three-phase system waveforms. Figure 5(a) shows the three-phase supply voltage with an equal magnitude of 230 V. Figure 5(b) shows the three-phase compensating current waveforms. This current is compensating for reactive power in the system and improved power quality. Figure 5(c) shows the three-phase supply current, the magnitude of the supply current is abnormal 0 to 0.02 sec. the magnitude of the supply current it maintains constant after 0.02 sec. the simulation run time is 0.06 sec. Figure 5(d) shows the load current waveform with magnitude 40 A. The magnitude of the current is abnormal up to 0.005 sec. after that is maintained balanced load. Figure 6 shows the THD value of the supply phase-current. The THD value is 6.31%. The value of supply current maintains nearly IEEE 519 standard.

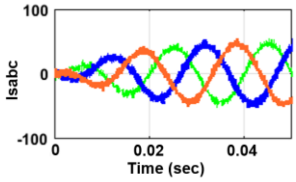
Figure 7 shows the hardware results of DSTATCOM. The hardware results are implemented by using OPAL-RT. Figure 7 shows the supply voltage and the magnitude of the supply voltage is 400 V. The magnitude of voltage balanced. The source current waveform is not distorted when connecting non-linear load. The FO-SMC controller has maintained a constant supply current. The load current is distorted by the non-linear load. The DC offset is presented in load current. The compensated supply current is reduced harmonic distortions. The compensating current generated by the DSTATCOM circuit. The overall performance of the system is good, with reduced THD 6.93%, and compensated reactive power.



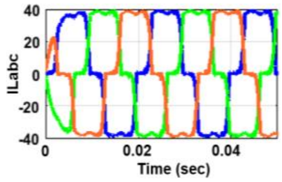
(a)



(b)



(c)



(d)

Figure 5. Three-phase output waveforms (a) three-phase supply voltage, (b) compensating currents, (c) three-phase source currents, and (d) three-phase load currents

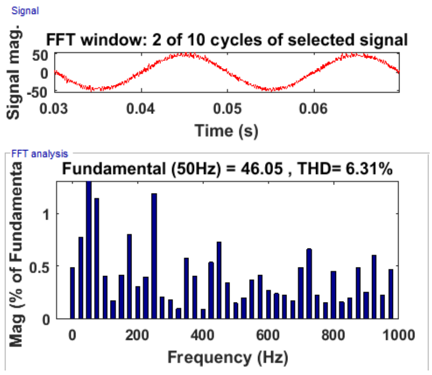


Figure 6. THD value of the supply current

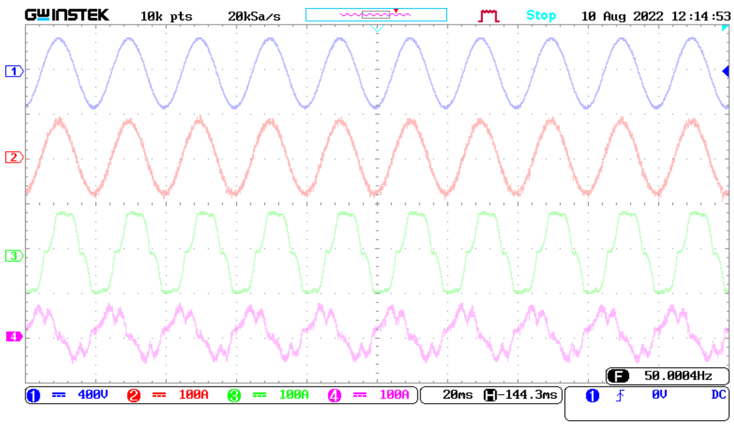


Figure 7. Hardware results of the DSTATCOM

5. CONCLUSION

This paper is presented FOSMC-based DSTATCOM for power quality improvement in distribution systems. The supply current harmonics, reactive power, and load balancing are common problems in the distribution system. The presented controller compensated reactive power, mitigated supply current harmonics, balanced load, and reduced THD in supply current. The presented system results are verified in MATLAB/Simulink software. The verified results are source current, load current, DSTATCOM current, and source THD. The hardware results are also presented in this paper. The presented controller has a very high response time, very high robustness, and high accuracy.

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